The third part of the paper is descriptive of an instrument for measuring electrical resistance without the aid of a magnetic needle or of resistance scales. It consists of two voltameter tubes fixed upon graduated scales, which are so connected that the current of a battery is divided between them, with one branch including a known and permanent resistance, and the other the unknown resistance to be measured. The resistance and polarization being equal, and the battery being common to both circuits, these unstable elements are eliminated by balancing them from the circulation; and an expression is found for the unknown resistance X in terms of the known resistances C and γ of the voltameter, including the connecting-wires, and of the volumes V and V′ of gases evolved in an arbitrary space of time within the tubes, viz.:—

$$X=\frac{V}{V'}(C+\gamma)-\gamma. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Changes of atmospheric pressure affect both sides equally, and do not therefore influence the results; but a reading at the atmospheric pressure is obtained at both sides by lowering the little supply-reservoir with dilute acid to the level indicated in the corresponding tube. The upper ends of the voltameter tubes are closed by small weighted levers provided with cushions of India-rubber; but after each observation these levers are raised, and the supply-reservoirs moved so as to cause the escape of the gases until the liquid within the tubes is again brought up to the zero-line of the scale, when the instrument is ready for another observation. A series of measurements are given of resistances varying from 1 to 10,000 units, showing that the results agree within one-half per cent. with the independent measurements obtained of the same resistances by the Wheatstone method.

The advantages claimed for the proposed instrument are, that it is not influenced by magnetic disturbances or the ship's motion if used at sea, that it can be used by persons not familiar with electrical testing, and that it is of very simple construction.

The following communications were read:—

I. "On the Change of Pressure and Volume produced by Chemical Combination." By M. BERTHELOT. Communicated by Dr. WILLIAMSON. Received April 25, 1871.

1. A singular question has arisen in the study of the gaseous combinations, viz. can the pressure be diminished in consequence of a reaction, at the moment it is accomplished, at constant volume, without loss of heat, so that the phenomenon of explosion comes from the excess of atmospheric pressure upon the inner pressure of the system, instead of coming from the inverse excess of the inner pressure? The discussion of this question, however special it appears at first sight, leads to general notions concerning chemical combination.

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2. The pressure depends upon the temperature evolved, and upon the state of condensation of the products. Let us determine this quantity.

Let t be the temperature produced by the real reaction, this being effected at a constant volume, admitting that the whole of the disengaged heat was employed in warming the products.

Let V be the sum of the volumes of the gaseous bodies in the initial system at 0° and $0^{m}\cdot 760$.

At the temperature t, the final system contains in general certain gaseous bodies.

Let V′ be the volume of these bodies, supposed to be brought, without changing their state, to 0° and $0^{m}\cdot 760$.

The relation $\frac{V'}{V}=\frac{1}{K}$ expresses the condensation produced by the reaction.

When certain bodies, contained in the initial system at 0°, or in the final system at $t°$, are in the solid or the liquid state, you can generally neglect their volume in comparison with that of the gas, when the pressures are not too considerable. Let us calculate the pressure during the reaction which takes place at a constant volume and at the temperature t, the initial temperature and pressure being 0° and H.

In admitting Marriotte's and Gay-Lussac's laws, the pressure will become

$$H\times\frac{1}{K}(1+\alpha t);$$

it will be greater than the initial pressure if $1+\alpha t>K$, less if $1+\alpha t<K$, or equal if $1+\alpha t=K$. Let us observe that $t=\frac{Q}{c}$, Q being the quantity of heat produced in the reaction, and c being the mean specific heat of the products between 0° and $t°$.

Let us develope this solution.

3. The pressure augments when the condensation is null, for instance chlorine and hydrogen, $K=1$; and especially when there is dilatation (combustion of acetylene by oxygen), t being always positive in a direct and rapid reaction between gaseous bodies.

4. On the contrary, the pressure diminishes if K is very great—that is, in the case of a system containing gaseous bodies transformed *entirely* into products which are in the solid or liquid state at the *temperature developed by the reaction*. This case is more rare than one would think at first sight, because very few compounds subsist wholly at the high temperature that would be developed by the integral union of their gaseous components. Generally a portion of these remain free at the moment of the reaction; but in the present state of our knowledge it is impossible to estimate the pressure corresponding to effects so complex.

It is necessary to consider that the present case must not be confounded with the case in which the products formed in the gaseous state and at the temperature of the reaction are liquefied or solidified under the influence of a subsequent cooling; for instance, the formation of water from its elements, or of chlorhydrate of ammonia from hydrochloric acid and ammonia, produce equally a diminution in the final pressure.

5. In theory the most interesting case is that in which the initial and final systems are wholly constituted of gaseous bodies, whose volume (calculated at 0° and $0^{\mathrm{m}}\cdot760$) is more condensed in the final than in the initial system. But this condensation is always comprised within very narrow limits, such as $K=4$ (formation of arsenious acid by the elements), $K=3$, 2, $1\frac{1}{2}$, &c.; so the fundamental condition

$$1+\alpha\frac{Q}{c}<K, \text{ or } Q<273\,(K-1)\,c,$$

that determines a diminution of pressure, should be realized only in very exceptional cases and when the heat evolved by an integral reaction is very little.

One can ascertain it in making the calculation by means of the specific heats at constant volume (deduced with ordinary coefficient from the specific heats at constant pressure which M. Regnault has determined for many bodies). One can also make the calculation in a more general manner, in admitting with Clausius that the specific heats at constant volume have an identical value for the atomic weights of elements, that this value is equal to 2, 4, the number found for $H=1$, and that it does not change from the fact of combination. W being the quantity of heat produced in a reaction between gaseous bodies calculated for atomic weights, and n the number of atoms in the reaction, the pressure will diminish only if

$$W<655n\,(K-1).$$

It is easy to see that this condition is not fulfilled in the combinations best known. Calculating, either by means of this formula or by means of the preceding, I have not succeeded in discovering any example of diminution of pressure among the numerous reactions I have examined in this present research.

Besides, it is sufficient to make the calculation for the reaction supposed integral, the conclusion being generally the same for the reaction supposed incomplete, that is to say in the case of dissociation, as it would be easy to prove.

6. Without further extending this discussion, I believe that a new general proposition relative to chemical combination can be deduced from it. It is known that every direct reaction which can be accomplished in a very short time between gaseous bodies with formation of gaseous compounds, produces a disengagement of heat: this is true for all reactions evolved by chemical forces alone, acting without help of any work done by exterior forces*. The new proposition is the following:—

The heat produced in a reaction of this sort, supposing it to be applied exclusively and without any loss to warm the products, is such that an augmentation of pressure always takes place at a constant volume, or, what is the same thing, an augmentation of volume at a constant pressure.

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* This proposition is contained in a more general one, which I have given in 'Annales de Chimie et Physique,' 4$^{\text{me}}$ série, t. xviii.

This proposition results not from any *à priori* deduction, but is verified by the whole of facts known to this day.

7. One may ask if the change of volume, in which the gases keep the whole heat produced by their mutual actions, is regulated by a simple law, analogous to those that have been observed when the gaseous combinations are brought to the same temperature; nevertheless it does not appear to be so.

Let us compare the formation of the different hydracids by means of their gaseous elements, which gives no change of volume when the gas is reduced at 0° and $0^{m}\cdot760$.

The formation of chlorhydric gas, HCl, produces 23,900 calories; the formation of bromhydric gas, HBr, produces 13,400 calories; the formation of iodhydric gas, HI, produces 800 calories. The specific heat of these gases being nearly the same under the same volume, it is clear that the quantities of heat aforesaid cannot produce an augmentation of volumes identical or proportional with simple numbers.

II. "Remarks on the Determination of a Ship's Place at Sea." In a Letter to Prof. STOKES. By G. B. AIRY, LL.D., &c., Astronomer Royal.

Royal Observatory, Greenwich, S.E.,
1871, April 5.

MY DEAR SIR,—In the last published Number of Proceedings of the Royal Society*, there are remarks by Sir William Thomson on the proposed method for determining the *locus* of a ship's place at sea, by making one observation of the sun's (or other body's) altitude, and founding, on this, computations of longitude with two assumptions of latitude; and there are suggestions, with a specimen of tables, for solving the spherical triangles which occur in all similar nautical observations, on the principle of drawing a perpendicular arc of great circle from one angle of a spherical triangle upon the opposite side.

In regard to this principle and the tables which may be used with it, I may call attention to the employment of a similar method by Major-General Shortrede, in his 'Latitude and Declination Tables,' pp. 148 and 180. In p. 150, line 11 from the bottom, it will be seen that the "column" gives the trial-value of the perpendicular arc by which the two right-angled triangles are computed. This is not the same (among the various elements which may be chosen) as Sir William Thomson's; but it is so closely related that in some instances the tabular numbers are identically the same as Sir W. Thomson's, though in a different order. General Shortrede's

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* Vol. xix. p. 259.